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Letter to the Editor

Investigation of physical and chemical properties of potential edible and non-edible feedstocks for biodiesel production, a comparative analysis

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ABSTRACT

Recently, non-edible vegetable oils have been considered as prospective feedstocks for biodiesel production. This is mainly attributed to their ability to overcome the problems of food versus fuel crisis related to edible oils. Globally, there are more than 350 oil-bearing crops identified as potential sources for biodiesel production. The evaluation of the physical and chemical properties of non-edible feedstocks is very important to assess their viability for future biodiesel production. Therefore, this paper aims to study the properties of some potential non-edible feedstocks. Moreover, the paper studies the physical and chemical properties of these promising crops and compares them with other edible oils. These oils include: crude *Calophyllum inophyllum* L. (CCIO), *Jatropha curcas* L. (CJCO), *Sterculia foetida* L. (CSFO), *Croton megalocarpus* L. (CCMO), *Moringa oleifera* L. (CMOO), patchouli (CPO), coconut (CCO), palm (CPaO), canola (CCaO), soybean (CSO) and *Pangim edule* (CPEO) oils. 14 Different properties have been determined and presented in this study.

1. Introduction

The shrinking supply of fossil fuels and the growing environmental concerns have made renewable energy an extraordinarily attractive alternative energy source for the future [1]. Biodiesel is a promising alternative fuel for diesel engines. Biodiesel is renewable, biodegradable non-toxic, portable, readily available and eco-friendly fuel [2].

Globally, there are more than 350 oil-bearing crops identified as potential sources for biodiesel production [3–6]. Recently, non-edible vegetable oils or second generation feedstocks have been considered as prospective feedstocks for biodiesel production. This is mostly attributed to their ability to overcome the problems of food versus fuel crisis related to biodiesel production from edible oils such as palm oil and sunflower. Moreover, they are easily available in many parts of the world especially wastelands that are not suitable for food crops, reduce deforestation rate, more efficient, more environmentally friendly, produce useful by-products and they are very economical comparable to edible oils [4,5,7].

Some examples of non-edible oilseed crops that are available worldwide are *Jatropha curcas* L., *Calophyllum inophyllum* L., *Sterculia foetida* L., *Madhuca indica*, *Pongamia pinnata*, *Hevea brasiliensis*, *Eruca sativa* L., *Melia azedarach*, *Terminalia catappa*, *Cerbera odollam*, *Croton megalocarpus*, *Terminalia bellerica* Roxb., *Azadirachta indica*, Rice bran and Microalgae [1,8–24].

The initial evaluation of the physical and chemical properties of non-edible feedstocks is very important to assess their viability for future biodiesel production. Therefore, this paper aims to review the properties of some potential non-edible feedstocks. Moreover, the paper studies the physical and chemical properties of these promising crops and compares them with other edible oils. These oils include: crude *Calophyllum inophyllum* L. (CCIO), *Jatropha curcas* L. (CJCO), *Sterculia foetida* L. (CSFO), *Croton megalocarpus* L. (CCMO), *Moringa oleifera* L. (CMOO), patchouli (CPO), coconut (CCO), palm (CPaO), canola (CCaO) and soybean (CSO) oils. 14 Different properties have been determined and presented in this study.

2. Literature review

2.1. Oil content of some promising biodiesel feedstocks

To consider any feedstock as a biodiesel source, the oil percentage and the yield per hectare are important parameters. Table 1 shows the estimated oil content and yields of different biodiesel feedstocks [5].

2.2. Influence of feedstock characteristics on biodiesel production

The feedstock characteristics such as FFA and fatty acid composition influence the biodiesel production process selection and final properties of biodiesel. Moreover, feedstocks with high MIU and titer require extra processing steps like filtration, centrifuging and heating [25].

2.3. Botanical description of some promising feedstocks

2.3.1. Calophyllum inophyllum L.

Calophyllum inophyllum L., commonly known as polanga or honne, is a non-edible oilseed belongs to the Clusiaceae family commonly known as mangosteen family. It is a large and medium sized, evergreen sub-maritime tree which grows best in deep soil or on exposed sea sands at altitudes from 0–200 m. The rainfall requirement is 750–5000 mm/year [12,20]. This plant has multiple origins including East Africa, India, Southeast Asia, Australia and the South Pacific [11,20,26,27]. The tree is a low-branching and slow-growing tree with two distinct flowering periods of late

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Nomenclature

CCIO	crude *Calophyllum inophyllum* L. oil
CCaO	crude canola oil
CCO	crude coconut oil
CCMO	crude *Croton megalocarpus* L. oil
CJCO	crude *Jatropha curcas* L. oil
CMOO	crude *Moringa oleifera* L. oil
CPaO	crude palm oil
CPEO	crude *Pangium edule* oil
CPO	crude patchouli oil
CSFO	crude *Sterculia foetida* L. oil
CSO	crude soybean oil

spring and late autumn [27]. In most parts of the world the tree shows two flowering and fruiting seasons. However, sometimes flowering may occur throughout the year [28]. The tree supports a dense canopy of glossy, elliptical, shiny and tough leaves, fragrant white flowers, and large round nuts. Its size typically ranges between 8–20 m (25–65 ft) tall at maturity, sometimes reaching up to 35 m (115 ft). The growth rate of the tree is 1 m (3.3 ft) in height per year on good sites. Its leaves are heavy and glossy, 10–20 cm (4–8 in.) long and 6–9 cm (2.4–3.6 in.) wide, light green when young and dark green when older. Fruits are spherical drupes and arranged in clusters. The fruit is at first pinkish-green later turning bright green and when ripe, it turns dark grey-brown and wrinkled. The tree yields 100–200 fruits/kg. In each fruit, one large brown seed 2–4 cm (0.8–1.6 in.) in diameter is found. The single, large seed is surrounded by a shell (endocarp) and a thin, 3–5 mm layer of pulp. The oil is tinted green, thick, and woodsy or nutty smell [20,26,27,29,30]. Oil yield per unit land area has been reported at 2000 kg/ha [20,30]. According to [31], the kernels have very high oil content of 75%. *Calophyllum inophyllum* L. has been considered recently as one of the most promising non-edible feedstocks for biodiesel production

2.3.2. *Jatropha curcas L.*

Jatropha curcas L. is a small tree or large shrub, up to 5–7 m tall, belonging to the Euphorbiaceae family which consists of around eight hundred species, which in turn belong to some three hundred and twenty-one genera. It is also known as Ratanjayot and physic nut. *Jatropha curcas* L. is a drought-resistant plant capable of surviving in abandoned and fallowed agricultural lands [4,32,33]. The plant is native to Mexico, Central America, Africa, India, Brazil, Bolivia, Peru, Argentina and Paraguay although nowadays it can be grown in pan tropical regions [4,20,33]. The tree is able to thrive in a number of climatic zones with rainfall of 250–3000 mm [34]. It is well adapted in arid and semi-arid conditions and has low fertility and moisture demand [9,20,35,36]. It can also grow on moderately sodic and saline, degraded and eroded soils. The ideal density of plants per hectare is 2500. It bears fruits from the second year of its establishment, and the economic yield stabilizes from the fourth or fifth year onwards and can live 30–50 years [9,20]. Seed production ranges from 0.1 t ha^{-1} $year^{-1}$ to more than 8 t ha^{-1} $year^{-1}$depending on the soil conditions [16,20]. The blackish seeds of *Jatropha curcas* contain toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins and phytates, to such levels that the seeds, oil and seed cake are not edible without detoxification [33]. The oil yields of *Jatropha curcas* is reported to be 1590 kg/ha [4,37,38]. According to [1], the oil content of *Jatropha curcas* seeds is (20–60%) compared to (40–60%) in kernels.

Table 1
Estimated oil content and yields of different biodiesel feedstocks [5].

Feedstocks	Oil content (%)	Oil yield (L/ha/year)
Jatropha curcas	50–60	1892
Calophyllum inophyllum	65	4680
Moringa oleifera	40	–
Soybean	15–20	446
Palm oil	30–60	5950
Coconut	63–65	2689
Rapeseed	38–46	1190
Sunflower	25–35	952
Peanut oil	45–55	1059
Olive oil	45–70	1212
Corn (germ)	48	172
Cottonseed	18–25	325
Rice bran	15–23	828
Jojoba	45–50	1818
Microalgae (low oil content)	30	58,700
Microalgae (medium oil content)	50	97,800
Microalgae (high oil content)	70	136,900

2.3.3. *Sterculia foetida L.*

Sterculia foetida L. is a large evergreen tree found usually in the western and southern parts of India, Burma, and Ceylon and occasionally in east tropical Africa, Borneo, Java, Sumatra, Indo-China, Malaya, and North Australia [19,39]. *Sterculia foetida* L. is a large, straight, deciduous tree growing up to 40 m in height and 3 m in girth, with the branches arranged in whorls and spreading horizontally [20,40]. The single large seed is surrounded by a shell and a thin 1–2 mm layer of pulp. The kernel of the seeds yields 50–60% of bland, light-yellow fatty oil. The oil can be used for culinary purposes but is frequently used as an illuminant; other possible uses are in the soap-making industry and surface-coating industry [41,42].

2.3.4. *Croton megalocarpus*

Croton megalocarpus is a member of the Euphorbiaceae family. It is a dominant upper canopy forest tree with heights ranging from15 to 40 m. It can grow between the altitudes of 1200 m and 2450 m respectively with mean annual rainfall of 800–1900 mm [16,20,43]. The tree is native to Burundi, Democratic Native: Republic of Congo, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda [43]. *Croton megalocarpus* is a tree indigenous to East Africa and the seeds have oil content of 40–45% [20,44]. A tree of *Croton megalocarpus* produces up to 50 kg of seeds and a hectare produces 5–10 t of seeds/year [16,20].

2.3.5. *Moringa oleifera*

Moringa oleifera is a member of the Moringaceae family, grows throughout most of the tropics, it is drought-tolerant and can survive in harsh, poor and infertile land. *Moringa oleifera* is indigenous to northwest India, Africa, Arabia, Southeast Asia and South America. However, it had distributed in the Philippines, Cambodia and Central and North America nowadays. *Moringa oleifera* oil is high in oleic acid which is around 70% of the total fatty acid profile [20,45]. The plant starts bearing pods 6–8 months after planting and reaches an average of 3 t of seed/hectare/year. The seed contains on average 40% oil by weight [16,20].

2.3.6. *Patchouli*

Patchouli [*Pogostemon cablin* (Blanco) Benth.; family: Labiatae] oil is one of the important natural essential oils used to give a base and lasting character to a fragrance in perfumery industry.

Patchouli oil is known to possess antifungal properties and is being used in skin infections, dandruff and eczema [46]. The plant is originated in India and Malaysia [47] and is now cultivated in China, Indonesia, India, Malaysia, Taiwan, the Philippines, Thailand, Vietnam and West Africa. Currently, Indonesia is the major producer of Patchouli with an annual production up to 550 t, which is around 80% of the total global production [46].

2.3.7. *Pangium edule*

Pangium edule belongs to Flacourtiaceae family and is also known as football fruit. It is native to the mangrove swamps of Southeast Asia (Indonesia, Malaysia and Papua New Guinea). It is a medium to large tree with large, glossy, heart-shaped leaves that are conspicuously veined and long-stemmed. The flowers are large and greenish; the sexes are separate. The fruit is oval and about the size of a large husked coconut, brown and rough-surfaced. The mature fruit is edible; however, the seeds are extremely poisonous and should not even be tasted [48].

2.3.8. *Elaeis guineensis (palm oil)*

Elaeis guineensis is a handsome tree reaching a height of 20 m or more at maturity. The tree is native to Cameroon, Cote d'Ivoire, Democratic Republic of Congo, Ghana, Guinea, Sierra Leone and Uganda. However, it has exotic distribution in China, Colombia, Congo, Costa Rica, Ecuador, Honduras, India, Indonesia, Kenya, Madagascar, Malaysia, Nigeria, Papua New Guinea, Philippines, Singapore, Solomon Islands, Sri Lanka, Tanzania, Togo, Venezuela and Zanzibar. The biophysical limits of the tree are as follow; altitude: up to 900 m, mean annual temperature: 27–35 °C and mean annual rainfall: 2000–3000 mm. The root system consists of primaries and secondaries in the top 140 cm of soil. Leaves can reach 3–5 m in adult tree. Leaf blades have numerous (100–160 pairs), of long leaflets with prominent midribs, tapered to a point; arranged in groups or singly along the midrib, arising sometimes in different planes [49].

2.3.9. *Cocos nucifera (coconut)*

Cocos nucifera tree is native to Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam. However, it has exotic distribution in Argentina, Benin, Bolivia, Brazil, Burkina Faso, Cameroon, Chad, Chile, China, Colombia, Cook Islands, Cote d'Ivoire, Ecuador, Fiji, French Guiana, Gambia, Ghana, Guinea, Guyana, Haiti, India, Jamaica, Kenya, Kiribati, Liberia, Madagascar, Mali, Marshall Islands, Mauritania, New Caledonia, Niger, Nigeria, Papua New Guinea, Paraguay, Peru, Samoa, Senegal, Sierra Leone, Solomon Islands, Sri Lanka, Surinam, Togo, Tonga, Uganda, United States of America, Uruguay, Vanuatu, Venezuela and Zanzibar. The trees have a smooth, columnar, light grey-brown trunk, with a mean diameter of 30–40 cm at breast height, and topped with a terminal crown of leaves. The biophysical limits of the tree are as follow; altitude: 520–900 m, mean annual temperature: 20–28 °C and mean annual rainfall: 1000–1500 mm. Tall selections may attain a height of 24–30 m; dwarf selections also exist. Leaves pinnate, feather shaped, 4–7 m long and 1–1.5 m wide at the broadest part. Leaf stalks 1–2 cm in length and thornless. Fruit roughly ovoid, up to 5 cm long and 3 cm wide, composed of a thick, fibrous husk surrounding a somewhat spherical nut with a hard, brittle, hairy shell. The nut is 2–2.5 cm in diameter and 3–4 cm long. The fruits are green at first, turning brownish as they mature; yellow varieties go from yellow to brown [50].

3. Material and methods

3.1. Materials

The seeds of *Calophyllum inophyllum* L., *Jatropha curcas* L., *Sterculia foetida* L. and *Pangium edule* were purchased from the Ministry of Forestry of the Republic of Indonesia (Bogor, Java, Indonesia). The extraction of crude *Calophyllum inophyllum* L. (CCIO), *Jatropha curcas* L. (CJCO) and *Sterculia foetida* L. (CSFO) oils was done using a screw extruder machine. However, to increase the yield from crude *Calophyllum inophyllum* L. oil (CCIO), hydraulic manual pressing machine was repeated several times. The extraction of crude *Pangium edule* oil (CPEO) was carried out via solvent extraction process, using *n*-hexane as the solvent. Crude *Croton megalocarpus* L. (CCMO), patchouli (CPO) and *Moringa oleifera* L. (CMOO) were supplied through personal communication. Crude palm (CPaO), soybean (CSO), canola (CCaO) and coconut (CCO) oils were purchased from the local market.

3.2. Equipment and properties analysis

Table 2 shows a summary of the equipment used in this study to analyze the physical and chemical properties beside the available test methods used to perform the analysis according to ASTM D6751 standard. These properties include: kinematic viscosity, dynamic viscosity, viscosity index, flash point, CFPP, density, specific gravity, caloric value, copper strip corrosion, oxidation stability, refractive index, transmission and absorbance. The next section will discuss some of the main properties which are covered in this study.

3.2.1. Kinematic viscosity, dynamic viscosity and viscosity index (VI)

Kinematic viscosity is defined as the resistance of liquid to flow. It refers to the thickness of the oil, and is determined by measuring the amount of time taken for a given measure of oil to pass through an orifice of a specified size [51]. Kinematic viscosity is the most

Table 2
Equipment list and test methods.

	Property	Equipment	Test method
1	Kinematic viscosity	SVM 3000 (Anton Paar, UK)	ASTM D445
2	Dynamic viscosity	SVM 3000 (Anton Paar, UK)	N/A
3	Viscosity index (VI)	SVM 3000 (Anton Paar, UK)	N/A
4	Flash point	Pensky-martens flash point—automatic NPM 440 (Normalab, France)	ASTM D93
5	CFPP	Cold filter plugging point—automatic NTL 450 (Normalab, France)	ASTM D6371
6	Density	DMA 4500 (Anton Paar, UK)	ASTM D1298
7	Specific gravity	DMA 4500 (Anton Paar, UK)	N/A
8	Caloric value	C2000 basic calorimeter (IKA, UK)	EN 14214
9	Copper strip corrosion	Seta copper corrosion bath 11300–0 (Stanhope-Seta, UK)	ASTM D130
10	Oxidation stability	873 Rancimat (Metrohm, Switzerland)	EN 14112
11	Refractive index	RM 40 Refractometer (Mettler Toledo, Switzerland)	N/A
12	Transmission	Spekol 1500 (Analytical Jena, Germany)	N/A
13	Absorbance	Spekol 1500 (Analytical Jena, Germany)	N/A

important property of biodiesel since it affects the operation of fuel injection equipment and spray atomization, particularly at low temperatures when an increase in viscosity affects the fluidity of the fuel [5]. Moreover, high viscosity may lead to the formation of soot and engine deposits due to insufficient fuel atomization. Kinematic viscosity is measured according to ASTM D445. Dynamic viscosity is also called absolute viscosity. It can be calculated by multiplying the kinematic viscosity with the density of fuel. Viscosity index (VI) is an arbitrary measure for the change of viscosity with temperature. It is used to characterize lubricating oil in the automotive industry.

3.2.2. Flash point (FP)

Flash point is another important property for any fuel. It is the temperature at which it will ignite when exposed to a flame or a spark. Flash point varies inversely with the fuel's volatility. Generally, crude oils have higher flash point compared to diesel which is usually more than 150 °C, while conventional diesel fuel has a flash point of 55–66 °C which is safe for transport, handling and storage purposes [5]. Flash point is measured according to ASTM D93 and EN ISO 3679.

3.2.3. Cold filter plugging point (CFPP)

Cold filter plugging point (CFPP) refers to the temperature at which the test filter starts to plug due to fuel components that have started to gel or crystallize. It is commonly used as indicator of low temperature operability of fuels and reflects their cold weather performance. At low operating temperature fuel may thicken and might not flow properly affecting the performance of fuel lines, fuel pumps and injectors. CFPP defines the fuels limit of filterability, having a better correlation [5]. CFPP is measured using ASTM D6371.

3.2.4. Oxidation stability (OS)

The oxidation of any fuels is one of the major factors that helps assess their quality. Oxidation stability is an indication of the degree of oxidation, potential reactivity with air, and can determine the need for antioxidants. Oxidation is influenced by some factors such as presence of air, heat, traces of metal, peroxides, light, or structural features of the compounds themselves, mainly the presence of double bonds [5,25,52]. The chemical composition of crude oil fuel make it more susceptible to oxidative degradation than fossil diesel fuel [53]. The Rancimat method is listed as the oxidative stability specification in ASTM D6751 and EN 14214.

3.2.5. Acid value

The acid number is a measure of the amount of carboxylic acid groups in a chemical compound, such as a fatty acid, or in a mixture of compounds [20,51]. Acid number can provide an indication of the level of lubricant degradation while the fuel is in service [20,54]. Acid value or neutralization number is expressed as mg KOH required to neutralize 1 g of fatty acid methyl esters and is set to a maximum value of 0.5 mg KOH/g in the European standard (EN14104) and ASTM D 664 [20,55,56].

3.2.5.1. Determination of acid value of the crude oil. The acid value can be calculated using the following equation:

$$AV = \frac{M_W N V}{W}$$

where $M_W \equiv$ Molecular weight of sodium hydroxide (NaOH). $N \equiv$ Normality of sodium hydroxide (NaOH) solution. $V \equiv$ Volume of sodium hydroxide (NaOH) solution used in titration. $W \equiv$ Weight of oil sample.

3.2.6. Copper strip corrosion

The copper corrosion test measures the corrosion tendency of fuel when used with copper, brass, or bronze parts. A copper strip is heated to 50 °C in a fuel bath for three hours followed by comparison with a standard strips to determine the degree of corrosion. Corrosion resulting from biodiesel might be induced by some sulfur compounds by acids; hence this parameter is correlated with acid number. The ASTM D130 standard mentions that the samples can have class 3 and EN ISO 2160 has class 1 [5,20,53,54,56].

3.2.7. Density

Density is the relationship between the mass and volume of a liquid or a solid and can be expressed in units of grams per liter (g/L). The density of diesel oil is important because it gives an indication of the delay between the injection and combustion of the fuel in a diesel engine (ignition quality) and the energy per unit mass (specific energy). This can influences the efficiency of the fuel atomization for airless combustion systems [5,20,51,57–59].

3.2.8. Refractive index (n)

The refractive index is a number that describes how light, or any other radiation, propagates when passing from one medium into another. More fundamentally, n is defined as the factor by which the wavelength and the velocity of the radiation are reduced with respect to their vacuum values.

4. Results and discussion

4.1. Physical and chemical properties of CCIO, CJCO, CSFO, CMOO, CCMO, CCO, CCaO, CSO, CPO, CPaO and CPEO

Table 3 shows the main findings of physical and chemical properties of crude CCIO, CJCO, CSFO, CMOO, CCMO, CCO, CCaO, CSO, CPO, CPaO and CPEO oils based on a comparison with some existing available literature. The differences in the results obtained in this study and of those presented in the literature are mostly attributed to the origin from which the oil was obtained. The next sections will discuss some of main the finding of this study.

4.1.1. Kinematic viscosity, dynamic viscosity and viscosity index (VI)

From Table 3, it can be seen that CSFO possesses the highest kinematic viscosity of 75.913 mm^2/s and 13.608 mm^2/s at 40 °C and 100 °C, dynamic viscosity of 69.408 mPa s at 40 °C, while CPO possesses the lowest kinematic viscosity among all oils with viscosity of 9.8175 mm^2/s at 40 °C and 2.2151 mm^2/s at 100 °C and dynamic viscosity of 9.2933 mPa s at 40 °C. It was also found that CCMO possesses the highest viscosity index of 224.2.

It was observed that CCIO possesses a lower kinematic viscosity compared to [26] 71.98 mm^2/s. However, CSFO possesses higher kinematic viscosity compared to [41] 49.7 mm^2/s. Whereas the viscosity of CJCO are within the limit mentioned by [32] (47–54.8 mm^2/s). While for CMOO the viscosity is slightly higher than that of [25,56] of 43.2 mm^2/s. For CCMO the result obtained in this study is much lower than that presented in [14] of 64 mm^2/s. The obtained viscosity of CCO in this study (27.64 mm^2/s) is slightly higher than that of [25,56] 27.26 mm^2/s. CPaO possesses a viscosity of 41.932 mm^2/s lower than that presented in [25,56] (44.79 mm^2/s). The viscosity of CSO is 31.739 mm^2/s is higher than that presented in [25,56] (2.87 mm^2/s). Finally, CCaO has a viscosity of 35.706 mm^2/s which is higher than that presented in [25,56] (34.72 mm^2/s).

It can be seen that all of these oils except CPO have very high viscosity. This is attributed to their large molecular mass and large chemical structure which indicates that all of these oils have good lubrication properties when used in CI engine. However, at

Table 3
Physical and chemical properties of CCIO, CJCO, CSFO, CMOO, CCMO, CPO, CCO, CPaO, CSO, CCaO and CPEO.

	Property	CCIO	CCIO[a]	CJCO	CJCO[b]	CSFO	CSFO[c]	CMOO	CMOO[d,e]	CCMO	CCMO[f]	CPO
1	Kinematic viscosity (mm^2/s) at 40 °C	55.677	71.98	48.091	47–54.8	75.913	49.7	43.4680	43.2	29.8440	64	9.8175
2	Kinematic viscosity (mm^2/s) at 100 °C	9.5608	–	9.1039	–	13.608	–	9.0256	–	7.2891	–	2.2151
3	Dynamic viscosity (mPa s) at 40 °C	51.311	–	43.543	–	69.408	–	38.9970	–	27.1570	–	9.2933
4	Viscosity index (VI)	165.4	–	174.10	–	184.80	–	195.20	–	224.20	–	−21.60
5	Flash point (°C)	236.5	221	258.5	210–240	246.5	158	263	–	235	–	146.5
6	CFPP (°C)	26	–	21	–	29	–	18	–	10	–	1
7	Density (g/cm^3) at 15 °C	0.951	–	0.915	–	0.937	0.9264	0.8971[g]	–	0.9100[g]	–	0.9466[e]
8	Specific gravity at 15 °C	0.952	0.896	0.9157	0.860–0.933	0.938	–	N/D	–	N/D	0.918	N/D
9	Acid value (mg KOH/g oil)	41.74	44	17.63	0.92–6.16	9.49	0.36	8.62	–	12.07	3.343	25.2
10	Calorific value (kJ/kg)	38,511	39,25	38,961	37,830–42,050	39,793	39,650	39,762	–	39,331	–	42,986
11	Copper strip corrosion (3 h at 50 °C)	1a	–	1a	–	1a	–	1a	–	1a	–	1a
12	Refractive index	1.4784	–	1.4652	–	1.4651	–	1.4661	–	1.4741	–	1.5069
13	Transmission (%T)	34.7	–	61.8	–	26.6	–	69.2	–	87.5	–	71.4
14	Absorbance (abs)	0.46	–	0.209	–	0.574	–	0.16	–	0.058	–	0.146
15	Oxidation stability (hour at 110 °C)	0.23	–	0.32	15.6	0.15	–	41.75	90.8	0.14	–	0.13

	Property	CCO	CCO[d,e]	CPaO	CPaO[d,e]	CSO	CSO[d,e]	CCaO	CCaO[d,e]	CPEO
1	Kinematic viscosity (mm^2/s) at 40 °C	27.640	27.26	41.932	44.79	31.7390	28.87	35.706	34.72	35.16
2	Kinematic viscosity (mm^2/s) at 100 °C	5.9404	–	8.496	–	7.6295	–	8.5180	–	–
3	Dynamic viscosity (mPa s) at 40 °C	25.123	–	37.731	–	28.796	–	32.286	–	–
4	Viscosity index (VI)	168.5	–	185.0	–	223.2	–	213.5	–	–
5	Flash point (°C)	264.5	–	254.5	267	280.5	254	290.5	246.5	–
6	CFPP (°C)	22	–	23	–	13	–	15	–	–
7	Density (g/cm^3) at 15 °C	0.9089[g]	–	0.8998[g]	–	0.9073[g]	–	0.9042[g]	–	0.9223
8	Specific gravity at 15 °C	N/D	–	N/D	–	N/D	–	N/D	–	0.923
9	Acid value (mg KOH/g oil)	N/D	–	N/D	–	N/D	–	N/D	–	6.036
10	Calorific value (kJ/kg)	37,806	–	39,867	–	39,579	39,600	39,751	39,700	–
11	Copper strip corrosion (3 h at 50 °C)	1a	–	1a	–	1a	–	1a	–	
12	Refractive index	1.4545	–	1.4642	–	1.4725	–	1.471	–	1.4705
13	Transmission (%T)	91.2	–	63.2	–	65.2	–	62.9	–	–
14	Absorbance (abs)	0.04	–	0.199	–	0.186	–	0.202	–	–
15	Oxidation stability (hour at 110 °C)	6.93	92.23	0.08	2.7	6.09	–	5.64	14.1	–

[a] [26].
[b] [32].
[c] [41].
[d] [56].
[e] [25].
[f] [14].
[g] at 40 °C.

the same time these high values of viscosities can negatively affect the volume flow and injection spray characteristics in the engine. At low temperature it may even compromise the mechanical integrity of the injection pump drive systems. Therefore, it is suggested that oil from the crops should be either blended with diesel fuel or transesterified to biodiesel to reduce the viscosity and improve the lubrication properties when used in CI engines.

4.1.2. Flash point (FP)

The results from Table 3 show that CCaO possesses the highest flash point of 290.5 °C followed by CSO with 280 °C while CPO possesses the lowest flash point of 146.5 °C. It can be seen except for CPO, all of these crude oils have very high flash points (>200 °C) which indicate that these oils are very safe for transportation, handling and storage. Moreover, all of the obtained results in this study are higher than that mentioned in [26] 221 °C for CCIO, [41] 158 °C for CSFO, [32] 210–240 °C for CJCO, [25,56] 254 °C for CSO and [25,56] 246.5 °C for CCaO except for CPaO which has a flash point of 267 °C [25,56] higher the obtained value in this study (254.5 °C).

4.1.3. Cold filter plugging point (CFPP)

From Table 3, it can be seen that (CSFO) possesses the highest CFPP point of 29 °C followed by CCIO with 26 °C, CPaO 23 °C, CCO 22 °C, CJCO 21 °C, CMOO 18 °C, CCaO 15 °C, CSO 13 °C, and CCMO with 10 °C. While CPO possesses the lowest CFP of 1 °C. As can be seen from Table 3, there is no any existing available literature results to compare our finding with them.

4.1.4. Calorific value (CV)

Calorific value is an important parameter in the selection of a fuel. The caloric value of crude oils is generally lower than of diesel because of its higher oxygen content [60]. This is proved in Table 3 as the calorific values of all these feedstocks are lower than diesel fuel (45,825 kJ/kg). However, it was observed that CPO possesses the highest calorific value of 42,986 kJ/kg followed by CPaO of 39,867 kJ/kg, while CCO possesses the lowest calorific value of 37,806 kJ/kg.

The obtained results for CCIO and CSO are lower than that presented in [25,26,56] of 39,250 kJ/kg and 39,600 kJ/kg respectively. However, the results of CSFO and CCaO are slightly higher than that of [41] and [25,56] of 39,650 kJ/kg and 39,700 kJ/kg respectively. Whereas the results of CJCO fall within the results presented in [32] of 37,830–42,050 kJ/kg.

4.1.5. Oxidation stability (OS)

Table 3 shows the results of oxidation stability of the present study. It can be seen that CMOO possesses the highest oxidation stability 41.75 h followed by CCO with 6.93 h and CSO with 6.09 h and CCaO with 5.64 h, while CPaO possesses the lowest oxidation stability of 0.08 h. From comparison with existing available literature, it can be seen that the oxidation stabilities of CJCO, CMOO, CCO, CPO and CCaO are much better than the obtained

values in the current study with 15.6 h, 90.8 h, 92.23 h, 2.7 h and 14.1 h respectively. This may be attributed to the long and improper storage times which deteriorate the oxidation stability of some of these feedstocks.

4.1.6. *Acid value*

Table 3 shows the results of acid values of some edible and non-edible oils in the present study. It can be seen that CCIO possesses the highest acid value 41.74 mg KOH/g followed by CPO with 25.2 mg KOH/g, CJCO with 17.63 mg KOH/g, CCMO with 12.07 mg KOH/g and CSFO with 9.49 mg KOH/g, while CPEO possesses the lowest acid value of 6.0362 mg KOH/g.

The comparison with existing results in the literature shows that the acid values of (CCIO) is higher than that of [26] (41.74 mg KOH/g). While (CJCO), (CSFO) and (CCMO) are lower than result presented in [32,41,14] with (0.92–6.16 mg KOH/g), (0.36 mg KOH/g) and (3.343 mg KOH/g) respectively.

4.1.7. *Copper strip corrosion*

Table 3 shows the results of copper corrosion of some edible and non-edible oils in the present study. It can be seen that all of these oils have class1a rating.

4.1.8. *Density*

The results from Table 3 show that the densities of CCIO, CSFO, CJCO and CPEO at 15 °C are 0.0951, 0.915, 0.937 and 0.9223 g/cm^3 respectively. While the densities of CMOO, CCMO, CPO, CCO, CPaO, CSO and CCaO measured at 40 °C are 0.8971, 0.9100, 0.9466, 0.9089, 0.8998, 0.9073, 0.9042 g/cm^3 respectively.

4.1.9. *Refractive index (n)*

Table 3 shows the obtained results of refractive index. It can be seen that CPO possesses the highest refractive index of 1.5069 followed by CCIO with 1.4784 while CCO has the lowest refractive index of 1.4545.

4.1.10. *Transmission and absorbance*

Table 3 shows the obtained results of transmission and absorbance characteristics. It can be seen that CCO possesses the highest transmission of 91.2% compared to 26.6% for CSFO. Moreover, the results show that CCIO possesses the highest absorbance of 0.46 abs compared to 0.04 abs for CCO.

5. Conclusion

This paper aims to review some of the potential non-edible feedstocks. In this paper the physical and chemical properties of some promising non-edible feedstocks were determined and compared with other edible oils. These oils include; crude *Calophyllum inophyllum* L. (CCIO), *Jatropha curcas* L. (CJCO), *Sterculia foetida* L. (CSFO), *Croton megalocarpus* L. (CCMO), *Moringa oleifera* L. (CMOO), patchouli (CPO), coconut (CCO), palm (CPaO), canola (CCaO), soybean (CSO) and *Pangium edule* (CPEO) oils. 14 Different properties have been determined and presented in this study. The main findings of this paper are as follow:

(1) CSFO possesses the highest kinematic viscosity of 75.913 mm^2/s and 13.608 mm^2/s at 40 °C and 100 °C, dynamic viscosity of 69.408 mPa s at 40 °C, while CPO possesses the lowest kinematic viscosity among all oils with viscosity of 9.8175 mm^2/s at 40 °C and 2.2151 mm^2/s at 100 °C and dynamic viscosity of 9.2933 mPa s at 40 °C. These high viscosities prohibit their direct use in diesel engines. Therefore, it is suggested that these oils should be either blended with diesel fuel or transesterified to biodiesel to reduce the viscosity and improve the lubrication properties when used in CI engines. It was also found that CCMO possesses the highest viscosity index of 224.2.
(2) CCaO possesses the highest flash point of 290.5 °C followed by CSO with 280 °C while CPO possesses the lowest flash point of 146.5 °C. It can be seen that all of these crude oils except CPO have very high flash points (> 200 °C) which indicate that these oils are very safe for transportation, handling and storage.
(3) CSFO possesses the highest CFPP point of 29 °C followed by CCIO with 26 °C compared to 1 °C for CPO.
(4) CPO possesses the highest calorific value of 42,986 kJ/kg followed by CPaO of 39,867 kJ/kg, while CCO possesses the lowest calorific value of 37,806 kJ/kg.
(5) CMOO possesses the highest oxidation stability 41.75 h followed by CCO with 6.93 h and CSO with 6.09 h and CCaO with (5.64 h), while CPaO possesses the lowest oxidation stability of 0.08 h. From comparison with existing results in the literature, it can be seen that the oxidation stabilities of CJCO, CMOO, CCO, CPaO and CCaO are much better than the obtained values in the current study with 15.6 h, 90.8 h, 92.23 h, 2.7 h and 14.1 h respectively. This may be attributed to the long and improper storage times which deteriorate the oxidation stability of some of these feedstocks.
(6) CCIO possesses the highest acid value 41.74 mg KOH/g followed by CPO with 25.2 mg KOH/g, CJCO with 17.63 mg KOH/g, CCMO with 12.07 mg KOH/g and CSFO with 9.49 mg KOH/g, while CMOO possesses the lowest acid value of 8.62 mg KOH/g).
(7) All of these crude oils have copper strip corrosion rating of class1a.

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